Genotypic and phenotypic correlations and principal component analysis of potato genotypes evaluated under multiple planting locations

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Abstract

A field experiment was conducted in spring season of 2023 by planting eight potato genotypes (3P29, 3P30, 3P31, 3P32, 3P35, 3P33, 3P34, and 3P36) in three locations: Bazian in Sulaymaniyah, Bardarash in Erbil, and Al-Qubba in Mosul. The aim was to determine the effect of genetic and environmental factors on traits and the extent to which they could be genetically improved by studying genotypic and phenotypic correlations and principal component analysis. A set of growth and yield traits were studied. The results of the genotypic and phenotypic correlation analysis showed that the two traits (number of primary stems and marketable tubers) are among the most important traits strongly correlated with total yield, making them key selection indicators that can be utilized in breeding programs to enhance productivity of the potato genotypes under study in Sulaymaniyah Governorate. Tuber dry matter weight and primary stem number also showed the highest values of genotypic and phenotypic correlations. Therefore, these traits can be used as selection indicators in genetic selection programs to improve potato productivity in both Erbil and Mosul Governorates. Principal component analysis supported the genotypic correlations results by showing that these traits clustered within the first component, proving that increasing the values of these traits directly improves yield.

Keywords: Potato; genotypic correlation; phenotypic correlation; principal component analysis; yield components

Introduction

Potatoes [*Solanum tuberosum* L.] are abundant in vital nutrients and energy, and they are among the most important and widely used crops. Their genus is Solanaceae, and there are around 2000 species in this family [6]. After wheat, rice, and corn, potatoes are the fourth most important crop for many countries' economies and staple foods [12].With a relatively high consumption per person, potatoes are one of the most popular vegetable crops. Potato tubers are an excellent source of numerous nutrients and provide high-quality food [18]. There is a wide range of factors that affect the chemical makeup of potato tubers, including genotype, tuber maturity, agricultural practices, storage conditions, and environmental factors [8]. As a general rule, 100 grams of peeled potato tubers provide 76 calories and 22–25 grams of dry matter. Carbohydrates make up 17 g, protein 2 g, fibre 0.5 g, fat 0.1 g, and ash 0.9 g of this dry stuff [7]. Potatoes are rich in many other nutrients as well. Potassium (400 mg), phosphorus (55 mg), magnesium (22 mg), calcium (7 mg), sodium (3 mg), iron (0.6 mg), and zinc (a little amount) are important minerals [19]. On 12645 hectares of land, Iraqis grew potatoes that weighed 21399.20 kg ha^{-1} and yielded 270591 tonnes [9]. Because yield depends on variety, growing area, and soil type, the environment plays a pivotal role in determining the development and productivity of potato cultivars [10]. In many parts of the world, potatoes are an essential part of the daily diet. Inadequate storage in facilities lacking many of the essential storage requirements [5], prevalent weather conditions throughout growth [17], and a lack of focus on selecting high-quality genetic genotypes are among the most serious issues confronting potato cultivation .

Developing better generations that can adapt to the environment and achieve higher yield is necessary to meet the increasing demand for food. However, improving yield through selection for economic traits has been limited due to the interaction between genetic and environmental factors, as well as the compensation mechanism among yield components and their relationship with other traits. To identify the causes of yield reduction, it is effective to obtain accurate estimates of the relative importance of these traits [3]. The relationship between genotype and environment is essential for precise selection and genetic progress. This is why plant breeders seek genetic improvement by conducting genotype tests in different seasons or locales [5]. Based on the data presented, the purpose of this study was to determine which potato features have the most impact on production in different growing regions and to use those findings to inform selection strategies for improving output. Researchers resorted to employing new, less lossy statistical techniques since correlations between traits are insufficient to explain the value of each trait in contributing to enhanced productivity. Principal Component Analysis [PCA] is a technique for decreasing sets of variables [13] and it does this for information..

Materials and Methods

The trial was carried out throughout the 2023 spring growing season at three different agricultural sites: Mosul, Erbil, and Sulaymaniyah. In each plot, eight different potato genotypes were planted: Sound(3P29), Lady Jane (3P30), Hermes (3P31), SHC 1010 (3P32), Acoustic (3P35), Paradiso (3P33), Lady Alicia (3P34), and Argana (3P36). As a basis for comparison and testing, the planting dates at Mosul (February 15, 2023), Sulaymaniyah (February 21, 2023), and Erbil (February 23, 2023) were all about the same. Deep, perpendicular ploughing and meticulous soil levelling were used to prepare the experimental fields in all three agricultural areas in the same manner. There were three blocks of fifteen experimental units apiece on the plot of land. There are four rows of tubers in the 8 x 3 m experimental unit, spaced 75 cm apart, with 25 cm between each row. A total of 53,333 plants were successfully grown per hectare. Apply 120 kg P_2O_5 /ha of monophosphate (19% P_2O_5) as phosphate fertilizers, and 160 kg of urea (46% N) as nitrogen fertilizers per hectare. The rate of potassium fertilizers, namely potassium sulphate (52% K_2O), was 160 kg K_2O_5 /ha as well [2]. Three blocks at three different sites made up the trial's RCBD design. The following characteristics were examined: total tuber count, number of marketable tubers per plant, shoot dry weight, plant height in centimeters, and number of primary stems per plant. yield in tons per hectare, tuber weight in grams, and tuber dry matter percentage. We computed the variance and covariance for each location in the research of the variables under consideration and tuber production per hectare. We also calculated the genetic and phenotypic variance. To determine the values of the correlation coefficients between traits, researchers employ the genetic and phenotypic covariance. [22, 25].

$$rPxy = \frac{\operatorname{cov}.Pxy}{\sqrt{(\sigma^2 Px)(\sigma^2 Py)}}$$

$$rGxy = \frac{\operatorname{cov}.Gxy}{\sqrt{(\sigma^2 Gx)(\sigma^2 Gy)}}$$

Where:
x and y = studied traits
σ^2P andσ^2G represent phenotypic and genotypic variance, respectively.
cov.P andcov.G represent phenotypic and genotypic covariance, respectively.
rPxy and rGxy represent phenotypic and genotypic correlations, respectively.

Principal component analysis (PCA) was was conducted using a correlation matrix. The analysis was based on eigenvalues, the percentage of variance explained (%), and the cumulative variance (%). Only PC1 and PC2 were discussed, as they explained the majority of the total variance and provided a clear distinction between the genotypes.
The results are presented in a table showing the eigenvalues, percentages of variance, and cumulative variance, according to the methodology of Abdi and Williams [1].

Results and Discussion:

Genotypic and Phenotypic Correlations

Genotypic and phenotypic correlations between the studied traits for the sulaimaniyah location:

Correlations between the researched features and genotypes of potatoes are shown in Table (1). There are strong positive and negative relationships between yield and vegetative characteristics, according to the findings. The levels of the genotypic correlations were generally higher than those of the phenotypic correlations, as seen in the table. A robust positive connection (r=0.5603) was observed between plant height and tuber weight. While there was a negative and statistically significant correlation between plant height and vegetative dry weight (-0.7953) and total number of tubers (-0.6905, respectively). The number of marketable tubers, tuber weight, and overall yield were all positively correlated with the number of primary main stems (0.9908, 0.7375, and 0.6558, respectively). The same holds true for the dry matter of plant components. There was a robust positive relationship between the total number of tubers and the dry matter content of the tubers (r=0.7231, r=0.8700, respectively). A positive connection of 0.4835 was found between total tuber count and tuber dry matter content, and a negative correlation of 0.4626 was found between total tuber count and tuber weight. Lastly, the amount of tubers that could be sold had a direct positive relationship with the weight and dry matter content of the tubers. Both variables were significantly correlated with total yield (r=0.7238), while tuber dry matter content was positively correlated with total yield (r=0.6096). A favourable phenotypic link with the number of primary stems and the number of marketable tubers was shown by the plant height characteristic, while a very significant phenotypic correlation with the tuber weight trait was also seen, reaching 0.4063, 0.4174, and 0.5568, respectively. There was a negative correlation between the characteristic and both the total number of tubers (-0.6902) and the dry matter content of the tubers (-0.6902). In line with the findings of Hajjam et al. [11], the results are presented here. The number of marketable tubers, tuber weight, tuber dry matter, and total yield were all positively correlated with the number of primary stems characteristic (0.9903, 0.7319, 0.5029, and 0.6555, respectively). The total number of tubers, tuber dry matter, and overall yield were all positively correlated with the dry weight of the vegetative body characteristic (r=0.7228, 0.8700, and 0.5489), respectively. There were positive phenotypic associations between the total number of tubers trait and tuber dry matter (0.4833) and total yield (0.4624), respectively. The phenotypic correlation between tuber weight and the same characteristic was -0.5346. Nasiruddin et al. [20] might be consulted for confirmation of these findings. There was a high positive correlation between the number of marketable tubers and tuber weight (0.7191) and overall yield (0.6624), as well as tuber dry matter (0.4617). Total yield was substantially linked with tuber weight (0.4912) and tuber dry matter (0.6096), both of which were determined by phenotypic analysis. According to these findings, there is a substantial genetic and phenotypic link between total yield and the two most essential features, which are the number of marketable tubers and the number of major stems. These characteristics make them important selection markers that can be used in a breeding program to improve the productivity of the potato genotypes being studied in Sulaymaniyah Governorate. Lembaga and Caesar, as well as Lavanya et al. [15]. Studying the trait correlations in a collection of potato genotypes yielded similar results [16].

Table 1. Values of genotypic (below diagonal) and phenotypic (above diagonal) correlations between the studied traits in Sulaymaniyah Governorate

Traits	X1	X2	X3	X4	X5	X6	X7	X8
X1	-----	0.4063*	-0.7953**	-0.6902**	0.4174*	0.5568**	-0.4972*	-0.1057
X2	0.4064*	-----	0.1329	-0.1590	0.9903**	0.7319**	0.5029*	0.6555**
X3	-0.7953**	0.1329	-----	0.7228**	0.1304	-0.1885	0.8700**	0.5489**
X4	-0.6905**	-0.1590	0.7231**	-----	-0.1477	-0.5346**	0.4833*	0.4624*
X5	0.4174*	0.9908**	0.1304	-0.1479	-----	0.7191**	0.4617*	0.6624**
X6	0.5603**	0.7375**	-0.1899	-0.5381**	0.7238**	-----	0.0981	0.4912*
X7	-0.4972*	0.5030*	0.8700**	0.4835*	0.4618*	0.0985	-----	0.6096**
X8	-0.1057	0.6558**	0.5489**	0.4626*	0.6625**	0.4948*	0.6096**	-----

** Significant at the 5% level   ** Significant at the 1% level.*

X1: Plant length (cm)   X4: Number of total tubers   X7: Tubers dry matter
X2: Number of primary stems   X5: Number of marketable tubers   X8: Total yield
X3: Vegetative dry weight   X6: Weight of tuber (gm)

Genotypic and phenotypic correlations between the studied traits for the Erbil location:

Table (2) shows the genotypic and phenotypic correlations between the traits under study for the potato genotypes, and that the genotypic correlation values frequently exceeded the phenotypic values. From the same table, we observe that plant height was genetically positively and strongly correlated with the quantity and weight of marketable tubers, at values of 0.8474 and 0.7834, respectively. Conversely, the same characteristic exhibited a very strong negative phenotypic correlation with the dry mass of the plant's vegetative components. and the total number of tubers (-0.7187 and -0.5208, respectively). Similarly, the number of primary stems was genetically strongly associated with the quantity of harvestable potatoes, potato weight, potato dry matter content, and overall yield. (0.6003, 0.5702, 0.5785, and 0.5733, respectively). Likewise, the same trait showed a strongly associated of phenotypic correlations with the number of marketable tubers, tuber weight, tuber dry matter content, and total yield. The dry weight of the vegetative parts exhibited a notable positive genotypic and phenotypic associations with both the total number of tubers and the plant's dry matter content, with genetic correlations of (0.4305 and 0.4424) and phenotypic correlations of (0.4304 and 0.4423). The total number of tubers showed a significant negative genotypic and phenotypic correlations with the number of marketable and weight of the tuber, with genotypic correlations of (-0.5762 and -0.6453) and phenotypic correlations of (-0.5760 and -0.6452). The trait of the number of marketable tubers showed strong positive genetic correlations were found with tuber weight and tuber dry matter content reaching (0.9494, 0.5779) respectively, and significantly with the total yield (0.5104). Phenotypically, the same trait was correlated with tuber weight, dry matter in tubers, and the total yield, reaching (0.9493 and 0.5777), respectively, and significantly with the total yield (0.5103). Tuber weight was strongly and phenotypically positively correlated with tuber dry matter (0.7144 and 0.7143, respectively) and with total yield (0.4999 and 0.4998, respectively). Tuber dries also indicated a strong positive relationship between genotype and phenotype with overall yield (0.5901 and 0.5900, respectively). Several recent studies confirm that key yield components such as the number of marketable tubers, average tuber weight, and structural traits of the plant (e.g., number of stems) exhibit strong positive genotypic and phenotypic correlations with total tuber yield. These traits consistently show direct positive effects on yield and are therefore considered reliable selection indicators in potato breeding programs aimed at improving productivity [14, 23]. The results show that tuber dry matter weight and the number of primary stems exhibited the highest phenotypic and genotypic correlation values. Therefore, these traits can be used as selection indicators in genetic selection programs to improve potato productivity in Erbil Governorate.

Table 2: Genotypic (below diagonal) and Phenotypic (above diagonal) Correlations Values Among the Studied Traits for Erbil Governorate

Traits	X1	X2	X3	X4	X5	X6	X7	X8
X1	-----	0.4728*	0.7187**	0.5207**	0.8473**	0.7834**	0.1815	0.3492
X2	0.4839*	-----	0.1309	-0.0937	0.5856**	0.5568**	0.5644**	0.5599**
X3	-0.7187**	0.1341	-----	0.4304*	-0.3004	-0.2613	0.4423*	0.1923
X4	-0.5208**	-0.0992	0.4305*	-----	-0.5760**	-0.6452**	-0.2692	0.3379
X5	0.8474**	0.6003**	-0.3004	-0.5762**	-----	0.9493**	0.5777**	0.5103*
X6	0.7834**	0.5702**	-0.2613	-0.6453**	0.9494**	-----	0.7143**	0.4998*
X7	0.1815	0.5785**	0.4424*	-0.2692	0.5779**	0.7144**	-----	0.5900**
X8	0.3492	0.5733**	0.1923	0.3380	0.5104*	0.4999*	0.5901**	-----

* Significant at the 5% level ** Significant at the 1% level.

X1: Plant length (cm)
X2: Number of primary stems
X3: Vegetative dry weight
X4: Number of total tubers
X5: Number of marketable tubers
X6: Weight of tuber (gm)
X7: Tubers dry matter
X8: Total yield

Genotypic and phenotypic correlations between the studied traits at the Mosul location:

According to Table (3), it was found that genetic correlation values were usually higher than phenotypic correlation values. This suggests that when it comes to determining the relationship between traits, genetic factors are more influential than environmental factors. The amount of tubers that could be sold and their weight were positively and phenotypically correlated with plant height (0.8877 and 0.6400 for genotypic and 0.8814 and 0.6400 for phenotypic, respectively). There was also a negative genetic correlation (-0.6573) and a phenotypic correlation (0.6573) between plant length and dry weight of vegetative mass and total number of tubers, as well as between plant length and dry weight of vegetative mass and total number of tubers, respectively. Shoot dry weight, tuber dry matter, and total yield were all favorably linked with the number of primary stems (r=0.8012, 0.7925, and 0.8698, respectively). A positive phenotypic correlation of 0.8008, 0.7921, and 0.8693 was observed for this feature in relation to shoot dry weight, tuber dry matter, and total yield, respectively. There was a highly significant positive association between the dry weight of the shoot and the plant's dry matter and total yield. Both genotypically and phenotypically, there was an inverse relationship between the total number of tubers and the weight and quantity of marketable tubers. Through phenotypic correlations of (-0.5585, -0.7218), genetic correlations of (-0.5634, -0.7219), and overall yield of (0.4903), the tuber demonstrated a robust positive relationship with yield. A strong positive genetic correlation of 0.8225 and a phenotypic correlation of 0.8167 were observed between the number of marketable tubers and tuber weight, indicating a highly significant relationship. There is a strong positive association between tuber dry matter and tuber weight (r=0.4399) in both genetic and phenotypic studies. There was also a very strong positive genotypic and phenotypic connection between total yield (0.6914) and tuber dry matter. Findings from studies of trait correlations and path coefficients in a collection of potato genotypes by Khayatnezhad et al. [14] and Sa'ad [23] are in agreement with these findings. The results show that in Mosul, the amount of tuber dry matter weight and the number of primary stems are important selection markers for increasing overall yield in the genotypes that were investigated.

Table 3: Genotypic (below diagonal) and phenotypic (above diagonal) correlations between the studied traits in Mosul Governorate.

Traits	X1	X2	X3	X4	X5	X6	X7	X8
X1	-----	-0.1991	-0.6573**	-0.7137**	0.8814**	0.6400**	-0.2099	-0.1766
X2	-0.1992	-----	0.8008**	0.2587	0.2233	0.4056	0.7921**	0.8693**
X3	-0.6573**	0.8012**	-----	0.4042	-0.3146	0.0609	0.8166**	0.6592**
X4	-0.7138**	0.2589	0.4043	-----	-0.5585**	-0.7218**	0.0553	0.4903*
X5	0.8877**	0.2228	-0.3169	-0.5634**	-----	0.8167**	0.1552	0.2499
X6	0.6400**	0.4058	0.0609	-0.7219**	0.8225**	-----	0.4399*	0.2373
X7	-0.2099	0.7925**	0.8167**	0.0553	0.1565	0.4399*	-----	0.6914**
X8	-0.1766	0.8698**	0.6591**	0.4904*	0.2519	0.2373	0.6914**	-----

* Significant at the 5% level ** Significant at the 1% level.

X1: Plant length (cm) X4: Number of total tubers X7: Tubers dry matter
X2: Number of primary stems X5: Number of marketable tubers X8: Total yield
X3: Vegetative dry weight X6: Weight of tuber (gm)

Principal Component Analysis (PCA)

According to Table (4) of the PCA at the Erbil site, the first and second components accounted for almost 79.9% of the overall trait variance when combined. This suggests that these two main factors account for the majority of the intrinsic variation among potato genotypes. According to Table (5), the first component yielded the highest loadings for the following traits: total yield (X8), number of marketable tubers (X2), tuber weight (X6), tuber dry matter (X7), and number of primary stems (X2). Specifically, dry matter weight and number of stems demonstrated very strong positive associations with total yield in the genotypic correlation data. The first part stands for the direct production axis, which shows that there are positive correlations between total yield and the main productive features. Both the total number of tubers (X4) and vegetative dry weight (X3) were moderately positively loaded with the second component. Although these two characteristics were positively correlated with one another, they had a weak or negative association with overall yield. The second part seems to stand for the axis of vegetative growth, which helps plants produce more in a roundabout way. The results of the genotypic correlations were corroborated by principal component analysis, which revealed that these qualities grouped within the first component. This indicates that raising the values of these traits directly increases yield.

The Sulaimaniyah location matrix's principal component analysis (Table 6) revealed that the first and second components accounted for about 79.9% of the total trait variation; thus, these two components explain the majority of the structure variation. The majority of characteristics, with the exception of vegetative dry weight (X3) and total tubers number (X4), had their highest loading coefficients in the first component, as shown in Table (7). In the genotypic correlation data, these are the same traits that shown strong positive relationships with total yield. By looking at the positive associations between the traits that comprise the yield, we can see that raising the levels of these traits obviously leads to improved output. The first component, representing the direct production axis, is well-represented by this correlation. On the other hand, the second part was defined by significant loadings for the dry weight of vegetative development (X3) and total number of tubers (X4) traits, which exhibited considerable positive correlations with each other and, to a lesser degree, with total yield. The axis of vegetative development and early formation is represented by this component, which indirectly contributes to higher overall production. It is concluded that the traits of number of marketable tubers and number of main tuber stems can be used as effective selection criteria for improving total yield, as there is agreement between the results of genotypic and phenotypic correlation and principal component analysis. To enhance potato output in different conditions, coordinated breeding and selection programs can target these qualities, which are among the best markers of stable genetic selection. Most of the variation between qualities can be summarized by two principal components, according to the results of the principal component analysis at the Mosul location (Table 8). The first and second components jointly explain 86.9% of the total variance. According to Table 9 of the loading coefficients, PC1 indicates a production axis because it has a negative signal with X1 and a high positive correlation with X2, X3, X7, and X8. When looking at the second component, we can see that X4 has positive loadings whereas X5 and X6 have severe negative loadings. This illustrates a second axis that harmonizes certain yield and growth characteristics. X2 and X7, which have strong and positive PC1 loadings, show coherence between the loading and correlation directions with yield attributes, so using them as selection criterion is logical according to the genotype/phenotype correlation tables at this location. In cases where the link between X5 and X6 and yield is weak or negative, PC2 data can be utilized to identify genotypes that combine X1 with beneficial levels while avoiding overly high levels of X6 and X5. This study's results are in line with those of Pradhan et al. [21], who found that yield-related traits were strongly associated with the first principal component, which accounted for over 80% of the variation in potato genotypes. The first component was also identified as the main production axis. In potato breeding programs, this lends credence to the idea that characteristics with high positive loadings on PC1 can be useful selection criteria. Results from the main component analysis of twenty-four potato genotypes by Seid et al. [24] are similarly in agreement with these findings.

Table 4: Eigenvalues and Explained Variance in Ebril

Principal Component	**Eigenvalue**	**Variance (%)**	**Cumulative Variance**
PC1	4.225	52.8	52.8
PC2	2.170	27.1	79.9
PC3	1.026	12.8	92.8
PC4	0.459	5.7	98.5
PC5	0.107	1.3	99.8
PC6	0.013	0.2	100.0
PC7	0.001	0.0	100.0
PC8	0.000	0.0	100.0

Table 5: Trait Loadings on the Eight Principal Components in Erbil

Trait	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
X1	0.410	-0.287	0.320	-0.053	-0.032	0.602	0.529	0.035
X2	0.334	0.277	0.142	-0.860	0.133	-0.158	-0.093	0.009
X3	-0.136	0.589	-0.371	-0.074	-0.489	0.112	0.487	-0.049
X4	-0.272	0.391	0.586	0.077	-0.029	0.307	-0.242	-0.520
X5	0.471	-0.050	0.001	0.101	-0.705	0.072	-0.511	0.053
X6	0.475	-0.023	-0.142	0.209	0.108	-0.375	0.206	-0.718
X7	0.325	0.397	-0.399	0.208	0.477	0.467	-0.282	0.089
X8	0.273	0.425	0.464	0.386	0.073	-0.377	0.180	0.448

Table 6: Eigenvalues and Explained Variance in Sulaymaniyah

Principal Component	Eigenvalue	Variance (%)	Cumulative Variance
PC1	4.225	52.8	52.8
PC2	2.170	27.1	79.9
PC3	1.026	12.8	92.8
PC4	0.459	5.7	98.5
PC5	0.107	1.3	99.8
PC6	0.013	0.2	100.0
PC7	0.001	0.0	100.0
PC8	0.000	0.0	100.0

Table 7: Trait Loadings on the Eight Principal Components in Sulaymaniyah

Trait	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
X1	0.423	-0.302	0.264	-0.106	0.214	0.419	0.599	0.027
X2	0.332	0.241	0.191	-0.831	0.147	-0.182	-0.085	0.043
X3	-0.177	0.580	-0.349	-0.089	-0.522	0.109	0.458	-0.072
X4	-0.248	0.369	0.562	0.071	-0.047	0.329	-0.260	-0.526
X5	0.497	-0.058	0.005	0.085	-0.692	0.071	-0.496	0.054
X6	0.481	-0.033	-0.118	0.216	0.099	-0.359	0.198	-0.731
X7	0.313	0.391	-0.407	0.222	0.481	0.463	-0.291	0.101
X8	0.297	0.439	0.471	0.393	0.083	-0.388	0.188	0.437

Table 8: Eigenvalues and Explained Variance in Mosul

Principal Component	Eigenvalue	Variance (%)	Cumulative Variance
PC1	3.740	46.8	46.8
PC2	3.205	40.1	86.9
PC3	0.801	10.0	96.9
PC4	0.166	2.1	99
PC5	0.059	0.7	99.7
PC6	0.022	0.3	100.0
PC7	0.004	0.1	100.0
PC8	0.001	0.0	100.0

Table 9: Trait Loadings on the Eight Principal Components in Mosul

Trait	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
X1	-0.348	-0.382	0.260	0.162	-0.431	0.632	-0.049	0.227
X2	0.426	-0.278	0.091	-0.533	-0.571	-0.213	-0.265	-0.084
X3	0.489	-0.039	-0.335	-0.141	-0.019	0.409	0.663	0.139
X4	0.327	0.331	0.557	0.093	0.023	-0.099	-0.000	0.675
X5	-0.152	-0.502	0.351	0.101	0.007	-0.487	0.593	-0.056
X6	-0.040	-0.536	-0.227	-0.290	0.520	-0.019	-0.255	0.489
X7	0.392	-0.281	-0.310	0.748	-0.165	-0.176	-0.216	0.080
X8	0.415	-0.220	0.481	0.079	0.436	0.331	-0.154	-0.467

Conclusion

Although comparable selection criteria emerged, it was demonstrated that the correlations among potato genotypes' growth and yield parameters varied across three testing conditions. In Sulaymaniyah, Erbil, and Mosul, the percentages of correlation studies showed a highly significant link between total yield and the number of marketable tubers, weight, and dry matter analysis. Further evidence for these findings came from principal component analysis, as these For the main component pertaining to production, the variables had the largest positive loadings across all locations. This finding emphasizes the durability of these important yield-enhancing traits, which can be used in crop improvement programs for various climates through breeding and selection. Potato plant breeders now have a solid foundation for identifying stable, high-yielding characteristics that govern yield amelioration thanks to the combined use of PCA and correlation.

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